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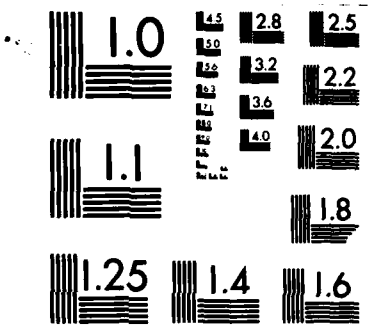

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The Second European Conference on Atomic and Molecular Physics

Paul Roman

22 May 1985

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The Second European Conference on Atomic and Molecular Physics was held in Amsterdam, The Netherlands, from 15 through 19 April 1985. This report focuses on presentations dealing with Rydberg systems, clusters, and coherent vacuum ultraviolet and x-ray ultraviolet generation. It also lists the topics of all other fields covered by the meeting.

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THE SECOND EUROPEAN CONFERENCE ON ATOMIC AND MOLECULAR PHYSICS

1 INTRODUCTION

The Second European Conference on Atomic and Molecular Physics (ECAMP) took place in Amsterdam, The Netherlands, from 15 through 19 April 1985.

About the Meeting

In 1981 the members of the European physics community launched an experiment: they convened in Heidelberg the First European Conference on Atomic Physics, trying to see if a major all-European meeting in this vibrant area of research could replace the several national and regional topical meetings of the past. The evident success of the convention led to the decision to add molecular physics to the agenda and repeat the ECAMP meetings every 4 years.

The Second ECAMP drew over 800 participants to Amsterdam. The majority of the scientists came from West Germany, followed closely by the French contingent. Some Spanish colleagues made a strong impression. There were some representatives from the Eastern-bloc countries, but the USSR speakers and participants did not turn up and did not send an explanation. A few people came from the Middle East and one from China. North America was represented by about eight scientists.

The conference was organized under the auspices of the European Physical Society, in cooperation with The Netherlands Physical Society and the Royal Netherlands Academy of Arts and Sciences. The meeting was technically hosted by the Institute for Atomic and Molecular Physics, which is one of the national institutes that constitute the Foundation for Fundamental Research on Matter. Financial support was provided also by several state and private sources in The Netherlands. All presentations took place at the rather new premises of the Vrije Universiteit (Free University). While the two lecture halls were splendidly equipped and the area set aside for the poster sessions was also quite adequate, many participants complained about the lack of small conference rooms where people could sit down and talk to each other more privately than in the midst of big crowds.

There were about 50 invited oral presentations divided into lectures, reviews, progress reports, symposia, and short hot-topics talks. With the exception of the lectures, the talks took place in two parallel sessions. Unfortunately there was hardly any discussion of the presentations. This was only partly due to the crowded program; the large number of people at the sessions also added a negative factor. Apart from the invited oral presentations, there were 425 contributed papers presented in poster sessions (one session each day, between the morning and afternoon talks). Perhaps this was a bit too much. In fact, I think the entire conference was somewhat too ambitious in its scope. There were also a small number of industrial exhibitors (I could not find any unusual products).

About the Nature of This Report

The talks covered all areas that are the designated topical fields of the European Physical Society's Division of Atomic and Molecular Physics: spectroscopy of atoms and molecules, collisions of atoms, ions and molecules, and chemical reactions. Clearly, no reporter can be competent (or courageous) enough to review all these areas, not to mention the fact that the enormous number of highly professional and often very specialized presentations were given in parallel sessions. I will restrict the narrative part of this report to only three major topical areas, partly because, in my judgment, they were emphasized by the organizers (clearly on account of their topical nature and fast development in the past few years), and partly because these three were the fields in which I felt most comfortable.

In Appendix A, I list by author and title all oral presentations (grouped in the classes as described above), and in Appendix B, I list the topics into which the poster presentations were arranged.

interested people may get from me xerox copies of all abstracts, as well as names and addresses (grouped by country) of all participants.

2 SELECTIVE NARRATIVE

Rydberg Systems

It appears that topics in the area of Rydberg atoms and molecules dominated the conference program. Indeed, this rather novel and quite amazing field of spectroscopy, which may also be called atomic or molecular physics at an unusual (very large) distance scale, provides not only an excellent proving ground for theoretical calculations and spectacular experimental demonstrations, but soon is likely to have practical applications in devices that require near-continuous tuning.

Rydberg systems are highly excited states of atoms (and more recently, of molecules) in which one electron (or sometimes even two electrons) has been raised to an orbital extending very far from the remaining ion core. Principal quantum numbers n as high as 200 or more have been successfully achieved. (Often also, nonzero angular momenta are excited.) Because such systems have an unusual size, an extremely low binding energy, and great structural simplicity, they have very striking properties, which have been extensively investigated by laser and microwave spectroscopy. Many of the Rydberg system properties can well be discussed by simple and elegant semiclassical arguments based on the correspondence principle. Rydberg atom spectra exhibit patterns that can be analyzed with the help of a small number of parameters, very similar to the phase shifts used for collision processes. The terminology "quantum defect" is used for these parameters, because the principal quantum number n must be replaced in such calculations by the quantity $n-\delta_l$.

The keynote address was given by Professor S. Haroche (École Normale Supérieure, Paris). After a general introduction to the subject, Haroche pointed out that by exciting the valence electron closer and closer to the ionization limit, the size and binding energy of a Rydberg state can be varied almost continuously. Consequently, all physical parameters related to size (or, equivalently, to n) can be tuned over a wide and unusual range of values. This leads to new and unexpected effects, especially in the area of interactions with electric and magnetic fields. The reason for this is that the strength of these interactions may approach or even exceed that of the Coulomb interaction between the ion core and the Rydberg electron. Haroche emphasized that because the theory of interaction between an atom and a (magnetic) field of arbitrary high amplitude is still incomplete, Rydberg atom experiments in high fields will soon lead to a better progress in this unresolved area. Apart from other implications, these advances will have important effects, for example, on astrophysics.

Of course, collisions of Rydberg systems with normal atomic or molecular systems, and especially the van der Waals interaction between two Rydberg systems, also show new features. Haroche feels that these phenomena will have various practical applications because they result from the large number of closely spaced levels in Rydberg systems, which are not available in conventional collisional situations.

But, foremost of all, he expects advances for practical exploitation from studies related to coupling Rydberg atoms to long-wavelength radiation. This coupling is unusually strong and leads to a whole range of radiative effects. Such studies are done not only in Haroche's laboratory but also at the University of Munich, and at the Massachusetts Institute of Technology and the National Bureau of Standards in the US. When coupled to resonant microwave cavities, Rydberg atoms furnish remarkable quantum electronics devices. In fact, maser action with only one atom in the cavity has been observed! One can look at such a system as if it were a giant antenna with a very high Q-value. It appears that a new area of research,

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tentatively called "cavity quantum dynamics," is emerging since, for Rydberg systems, quantum effects must be taken into account even at microwave frequencies.

A second major talk, by Professor J.C. Gay (representing the Hertz Spectroscopic Laboratory of the École Normale Supérieure, Paris) reported on recent theoretical progress that he and Dr. D. Delande achieved in the study of the interaction between Rydberg atoms and very strong electric and magnetic fields. This, as I noted above, is a difficult area. Gay emphasized very strongly the usefulness of the SO(4) noninvariance algebra (dynamical group) associated with the Coulomb field. As a one-time "elementary particle theorist," I could not help smiling when Gay made a flowery "hard-sell pitch" for this powerful technique. In fact, the concept was introduced by the Russian physicist Fock about five decades ago, and its generalization to other possible dynamical groups (relevant, presumably, for subnuclear dynamics) became quite a fashion with high-energy theoreticians in the late 1960s and early 1970s. It was gratifying to see that, finally, atomic physicists take the idea of dynamical groups seriously exactly in the area from which it originated and where it belongs. In any case, Gay demonstrated very clearly that these group theoretic calculations indicate picturesquely how, for the highly excited Rydberg states, the energy levels and the eigenfunctions become completely tunable in a controlled way, by simply varying the external electric and magnetic fields appropriately. He also indicated possible applications to the study of electronic collisions and other phenomena, including the area of photochemistry. Gay concluded his report by describing briefly careful experiments recently concluded in his institute, in which the researchers used crossed electric and magnetic fields to demonstrate and to study in detail the phenomenon of atomic diamagnetism. The experiments apparently fully verified the theoretical predictions.

These last points in Gay's talk closely tie up with the presentation of the Bielefeld group (read by Dr. K.H. Welge from the Physics Faculty of the Bielefeld University, West Germany) reporting on laser spectroscopy of the hydrogen atom in strong electric and magnetic fields. Welge, apparently for the first time in this rapidly developing discipline, used two-photon excitation through the n=2 state as an intermediary step, employing vacuum ultraviolet and ultraviolet laser radiation in a crossed laser beam-atomic beam arrangement:

$$H(n+1)+VUV \longrightarrow H(n+2)+UV \longrightarrow H^*.$$

Both the vacuum ultraviolet (VUV) and the UV radiation were independently tunable and linearly polarized. Systematic studies have been made with electric fields up to 8 kV/cm strength. But more exciting are the studies in external magnetic fields. The details of this research were actually reported in a contributed post-deadline paper presented by Dr. A. Holle of the Bielefeld group. He explained that magnetic fields up to 6-Tesla strength were applied. (A superconducting split-pair magnetic system was used.) The experiments showed, for the first time, quasi-Landau resonances in the hydrogen atom. Unfortunately, I was unable to assess the priority of these results relative to the work of Gay's group in Paris. Incidentally, Welge (correctly) lamented the fact that, so far, there are no results for Rydberg *molecules* in strong electric or magnetic fields.

Yet another contributed paper was presented in the area of interactions between a strong external magnetic field and Rydberg atoms (lithium, in this case). P. Cattani and associates (A. Cotton Laboratory, Centre National de la Recherche Scientifique [CNRS], University of Paris-Sud) explained their technique in which standard laser-spectroscopy methods were used (employing a tunable pulsed laser system in the ultraviolet range). They produced a magnetic field up to 5-Tesla strength,

with the help of a pair of superconducting coils. The researchers investigated atomic diamagnetic structures at relatively low fields, but in the inter-l-mixing region; they studied level anticrossing features, and they investigated electric field ionization processes in the presence of magnetic fields.

One more invited talk in the area of Rydberg systems caught my attention: Professor P. Zoller (Institute of Theoretical Physics at the University of Innsbruck, Austria) presented his calculations on autoionizing states in intense laser fields that can be used to relate the process of photoionization from Rydberg states to stimulated bremsstrahlung and above-threshold ionization. The autoionizing states appear as intermediate resonances and final states in multiphoton ionization (MPI) experiments. The investigations of this kind are concerned with the dynamics of MPI when the interaction of the electrons with the laser beam competes in strength with the electron correlation in atoms. In his work, Zoller used a multichannel quantum-defect-theory parametrization of the relevant dipole matrix elements. Among other results, he came to the conclusion that his formalism suggests an adiabatic approximation.

In order to conclude this section of my report, I will take brief note of some contributed papers that, with my very limited knowledge in the area, I found challenging.

A group from the University of Mainz, West Germany (U. Dinger and others in cooperation with T. Kühl, Darmstadt), reported on the production of In(29p) Rydberg states by means of double-resonant two-photon excitation, and described their detection by ionization in a longitudinal electric field. The available methods have been developed to reach high selectivity in on-line measurements of isomer and isotope shifts of short-lived nuclei, and they extend the conventional collinear laser spectroscopy.

C. Leonard and R.-H. Rinkleff (Institute for Atomic and Molecular Physics, University of Hannover, West Germany) observed superradiance in alkaline-earth atom Rydberg states. They also found that competition between different superradiant transitions results in drastic intensity variations. This is an unexpected phenomenon.

J. Neukammer and others (Institute for Atomic and Solid State Physics, Free University, Berlin) reported an amazing "first." They have succeeded in exciting and detecting 6snd Rydberg states of Ba with n up to 280! These are surely the "largest" atoms ever produced in a lab. Collisional (Penning) ionization of Rydberg states was the primary mechanism they used.

R. Blatt and E. Matthias (Institute for Atomic and Solid State Physics, Free University, Berlin) described a method that exploits the strong diamagnetism of Rydberg states to deflect such systems in an inhomogeneous magnetic field. They showed that these forces are also suited to store neutral Rydberg atoms in a static magnetic trap. Their approach is based on the observation that atomic diamagnetism is prevailing for even moderate magnetic fields, provided the atoms are in highly excited states, $n>100$. In particular, the researchers derived conditions for the maximum velocity of the particle to be trapped and for the maximum magnetic field to be supplied, both as a function of n. They claim that for realistic experimental conditions, a typical well depth of 10^{-13} eV can be achieved, which is considerably more than for other proposed neutral atom traps.

Finally, a commendation is due to F. Biraben and L. Julien (Hertz Spectroscopic Laboratory, Paris) for having devised a high-precision, Doppler-free, two-photon spectroscopy method to measure the hydrogen Rydberg constant with a relative precision of 1.3×10^{-10}, by studying the 2S-nS and 2S-nD transitions for high ($n>10$) nS and nD levels.

Clusters

The term "cluster" is used for relatively small aggregates of atoms (or

molecules), either neutral or ionized. Such systems have been successfully prepared and analyzed from various points of view. They have attracted considerable interest in the past few years. This rapidly developing science of unusual states of matter not only enhances our basic understanding of interactions on the atomic scale, but many people also feel that it has important potential for technological applications. Catalysis and photography are often mentioned as obvious examples.

The size of a "cluster" can vary considerably. Typically, in a cluster A_n the number n of constituents (identical or different) is large enough so that one cannot consider A_n to be a molecule. On the other hand, n should be less than the number of constituents that would be needed to form a speck of matter with clear liquid or solid bulk properties. (In some cases n may be very small, even dimers with n=2 are considered clusters, provided that there are chemical reasons why one cannot talk of a molecule.)

Obviously, the physics of clusters is the link between atomic/molecular physics on one hand and condensed matter physics on the other. Futhermore, aggregates of atoms on solid surfaces also have special properties, resulting in new phenomena.

The leading invited talk in the area of clusters was delivered by Professor H. Haberland (University of Freiburg, West Germany). After a brief general introduction, he called our attention to two important features. First, he said, even for quite large clusters, a significant fraction of the constituents is on the surface of the aggregate; hence, established results of surface science ought to be taken more seriously when working with clusters. Second, he found it important to always keep in mind that cluster properties scale linearly with respect to either the number of constituents or the cluster radius. He briefly discussed configurations and symmetries of smaller clusters and pointed out the amusing fact that small clusters often exhibit the infamous five-fold symmetry (forbidden in standard crystallography because of not being compatible with periodicity but nevertheless observed recently in some transitional states of bulk matter as well).

In the second part of his talk, Haberland reviewed in some detail the supersonic source method of producing clusters (utilizing adiabatic cooling). This method works particularly well for rare gases. But he pointed emphatically to a serious experimental problem. After production of a cluster beam, usually it is necessary to ionize it to allow for energy filtering and, in particular, for mass-spectroscopic selection and identification of clusters with specific number of constituents. Now, the ionization process almost invariably will lead to "evaporation" or complete fragmentation of the clusters, so one does not exactly know what system one is dealing with. He discussed possible remedies and indicated that gas discharge is a good way for efficient ionization. Haberland reminded his listeners also of another problem one encounters when rare gas clusters are produced with the supersonic method: one is bound to get not only varied cluster sizes, but also varying temperatures in the cluster beam.

In the remaining part of the talk, Haberland described some of the recent experiments done in his research group. The highlights are:

1. He succeeded in producing argon atom clusters up to size n=20,000.
2. Detailed data were obtained and collected in experiments aimed at both photoionization and Penning ionization of Ar_n clusters (large interwall of n).
3. With small Ar_n clusters, an analog of point-defect formation (known in crystal physics) was discovered.
4. In an entirely different class of experiments clusters of molecules with high dipole moment (H_2O, NH_3) were explored. In particular, electron affinities of $(H_2O)_n^-$ ionized clusters (in a broad range of n) were measured.
5. Photo processes in both H_2O and rare gas clusters were studied (but no details were presented at the meeting).

Future plans, Haberland told his audience, concern photo processes with sodium clusters (such as $Na_n^- + h\nu \longrightarrow Na_n + e^-$). Finally, to the great excitement of many participants, he promised that he will attempt optical spectroscopy on single cluster ions!

A second major talk on clusters was presented by Professor L. Wöste (Experimental Physics Institute of the École Polytechnique Féderale de Lausanne, Switzerland). This research progress report reviewed recent work done on the spectroscopy and dynamic properties of metal atom clusters. Wöste and his colleagues at Lausanne cooperate with many other institutions, such at French universities at Lyon and Orsay, and German institutions at Freiburg and Darmstadt.

Metal atom clusters are more sophisticated objects than rare gas atom aggregates and may be produced by evaporation and subsequent supersonic adiabatic expansion, but this works only if the metal has a low evaporation temperature (such as sodium or mercury have). For heavier metals, like silver, laser evaporation or sputtering arrangements must be used. Wöste described the latter in some detail.

Next he made a strong point, telling us that two-photon ionization, if combined with mass spectroscopy, is a very powerful tool for probing electronic excitation bands of very small clusters. He described his experimental arrangement in which two laser beams were used: one at a fixed frequency, the other tuned. Highlights of his results are:

1. State-selective ionization efficiencies higher than 20 percent were found for alkali dimers.

2. Particle temperatures could be ascertained in the same experiment, with the surprising result that the temperature of the dimers emerging from supersonic or laser vaporization sources could be made as low as 7°K, but in the case of sputtered particles one gets about 1240°K.

3. Spectra of highly cooled Na_3 clusters exhibited well-resolved vibrational and rotational sequences, indicating significant changes of geometry as a consequence of electronic excitation.

4. Highly excited autoionizing Rydberg states were produced when the ionization potential was crossed. These processes provide additional information about the ground state of the cluster ion. (However, spectral resolution beyond the dimer size has not yet been found feasible.)

5. In experiments with silver ion clusters, the researchers successfully created conditions in which the system consisted of only single-size clusters. The electron affinity and the chemical reactivity of these cluster ions was determined by using a quadrupole drift tube.

6. Pronounced size effects were found and were demonstrated with photoemulsion experiments. This basic research may have important implications for the engineering of catalytic processes, since it may allow one to distinguish between the homogeneous and inhomogeneous mechanisms.

At the end of his report Wöste strongly pointed at an experimental difficulty which his group repeatedly experienced. They found that with growing cluster size, clear distinction between the parent ions and the fragments became increasingly difficult. The reason for this can be found in the fact that excitation and ionization processes are always accompanied by strong fragmentation channels.

Among the 14 or so contributed papers on clusters, I found the presentation by M. Knapp et al. (University of Konstanz Physics Faculty, West Germany) the most thorough and original. The paper reported on electron attachment to neutral molecular clusters, about which we did not hear in the invited talks. Actually, only very few studies have been reported worldwide in this area. These negatively charged cluster ions are unstable or metastable with respect to dissociation or autodetachment. The clusters were produced in the usual way, by expansion of the pure gas through a nozzle. Positively and negatively

iarged clusters were generated with a ilsed electron beam that had variable iergy. Mass spectrometric investiga- ions were done for both positively and egatively charged clusters under the ime condensation conditions, and size istributions of cluster ions from the ime initial ensamble of neutral clus- ers were obtained. Negatively charged luster ions were seen with the follow- ig compositions:

$$(CO_2)_n^-,\ n \geq 2;\ (CO_2)_m O^-,\ m \geq 0;$$
$$(NO_2)_m O^-,\ m \geq 0.$$

it the stoichiometric cluster ions $NO_2)_n^-$ were not observed, as opposed to $NO_2)_n^+$ clusters. Size distributions of arge clusters up to 2000 monomer units ere analyzed, and both negative and ositive ions showed nearly the same imodal type distribution. (This is in ontrast with the behavior of small lusters.) For very low (about 1 eV) lectron energies the researchers ob- erved weak local intensity anomalies in he size distribution of negative clus- ers, superimposed on the broad intensi- y maximum. They tentatively attributed hese anomalies of large cluster ions to table configurations which are inde- endent of the sign of the charge. Some bservations seemed to be incompatible ith earlier reports in the literature hich assumed that the neutral precur- ors of positive cluster ions are larger y a factor of two to four.

Another group from the University f Konstanz (under the leadership of D. reisele) reported on the dissociation f xenon cluster ions. In a sense, this ork has some relationship with the pre- eding one. The scientists determined hat the evaporation of monomers follow- ng electron impact ionization is the ecisive process for the evolution of nomalies in the mass spectra of large enon ion clusters. They measured the vaporation rates with a modified time- f-flight mass spectrometer for cluster izes up to 90. One of their final onclusions was that, independent from he size distribution in the neutral luster beam, the intensity anomalies in the mass spectra of Xe_n^+ are due to the existence of particularly stable or unstable cluster ions.

The topic of metal cluster ions, reviewed in one of the invited papers discussed above, was further elaborated on by a contributed report from the Bielefeld group (W. Begeman and others). They described their work on continuous beams of mass selected Al_n^+ and Cu_n^+ clus- ters, which were produced by sputtering, accelerated, and then focused either onto the cathode of a CuBe particle multiplier or into a quadrupole mass separator. They observed strong inten- sity variations in the spectrum. Since the experiments involved free ionic cluster beams, the peak heights in the spectrum reflected the actual cluster intensities and permitted an exploration of the chemical stability of the species of interest. For example, such experi- ments confirmed the theoretically as- sumed D_{2h} structure of Cu_4^+.

Finally, I want to report on the careful work of C. Bréchignac and Ph. Cahuzac (Cotton Laboratory, CNRS, Orsay, France) who, in contrast to most earlier work in this area, reported on *high-resolution* studies of photoionization profiles of small potassium clusters, from K_3 to K_8, in their respective threshold regions. The K_n clusters were formed in a supersonic expansion and photoionized with the light of a tunable pulsed UV laser. They were mass-selected by a time-of-flight system. The scien- tists found clear evidence of different behavior in ionization potential pro- files between even- and odd-numbered clusters. They said that the linear rising in the curves for K_3, K_5, and K_7 suggests similar geometrical structures for neutral and ion clusters containing an odd number of atoms. On the other hand, they noted that the frequently discussed odd-even alternation of ioni- zation potentials of alkali metal clus- ters is no longer evident when high resolution is used.

Coherent VUV and XUV Generation

One area where laser and other quantum-optics research and development

; still rather far from satisfying the :eds of materials science, spectro-:opy, and defense projects is the effi-.ent generation of sufficiently high-)wer, coherent (and preferably broadly ınable) electromagnetic radiation for ıvelengths well below 200 nm. Surely ıe has many reasons to hope for pro-'ess in the development of devices that)uld really function well in the hard .traviolet, VUV, x-ray ultraviolet :UV), and, hopefully, the proper x-ray :gion.

I was therefore quite thrilled to :e that the conference organizers plan-:d a special all-afternoon symposium to)ver this field, even though, strictly)eaking, the topic is not in the area atomic physics, narrowly defined.

As it turned out, the symposium lew Techniques for Generating Coherent :V and XUV" did not come out as a sym-)sium: it consisted merely of three ıcorrelated and unconnected major lec-ıres. There was no interaction and no .scussion. Moreover, despite its title, ıe symposium had very little to say)out new techniques. Nevertheless, .nce all three talks covered topics in ıich different segments of the physics)mmunity are deeply involved, I find it)propriate to summarize the highlights the talks.

In the opening address, Professor Billardon (Laboratoire pour l'Utili-ıtion du Rayonnement Électromagnetique :search Institute of the CNRS, at the ıiversity Paris-Sud in Orsay) reviewed, ı an oversimplified but pedagogically ıpressive manner, the working princi-.es of free electron lasers. He de-'ribed in some detail the particular :orage-ring realization used at Orsay. ıis setup has a wiggler spacing of cm, has a total active length of 3 m, and uses a 3-kG undulator field) operate on the electron beam that has ı energy of around 500 MeV. Billardon ıen elaborated on the May 1984 success the researchers (well reported and ıblicized in both the scientific and ıe reviewing literature), which led to ıe definitive observation of coherent light in the UV region. In these experiments the electron beam was stimulated by a Nd/Yag laser focused into an optical clystron architecture. Higher coherent harmonics in the VUV region were also verified and studied. Presently, the Orsay group can generate harmonics up to the sixth order, and the radiation has an average power of 20 mW with a peak power of 200 W. Unfortunately, the mirrors show big (5 percent) losses, so that the efficiency is poor. The scientists plan to make improvements on the storage ring (and the mirrors, I hope), and to extend the active region to 5-m length. They expect that by 1986 they will be able to produce continuously tunable radiation from 500 nm down to 100 nm (or less) with a 10 percent efficiency and an average power of several watts. But no solid statement as to how this will be achieved was put forward. If the scientists succeed in creating the 10th harmonic, the wavelength would be about 6 nm, well toward the lower edge of what nowadays qualifies as "hard XUV." But this is still a dream.

The second speaker was Professor G.J. Pert (University of Hull, UK). He presented a well-organized review of the present state of the art in generating XUV laser action by methods utilizing plasma as the source of radiation. He paid special attention to work based on recombination spectra excitation methods. Apart from his own group's well-known pioneering work at Hull and Rutherford-Appleton (which used carbon fibers), he also reviewed briefly the Orsay reports of having observed gain at 10.5 nm in lithium-like recombination spectra (as opposed to his own hydrogen-like spectra). He noted that at Princeton the researchers used radiation cooling of the plasma instead of adiabatic cooling. Unfortunately, he did not elaborate on this point, and no detailed analysis was presented. Next, he discussed the possibility of pumping by electron collisions which, in principle, could give higher gain than recombination. Pert referred briefly to the inconclusive 1978 reports from the lab of

'gradow in the USSR, and then dis-
:d at some length the recent, well-
›rated results from Livermore with
-like spectra in selenium (as well
:trium). These experiments used two-
l illumination of coated foils.
ıt reports indicate, Pert pointed
that the pumping occurred again by
ıbination (rather than some electron
ısion mechanism).

Pert concluded his review by the
›wing summary:

1. Experiments decisively demon-
:ed the feasibility of manageable
lasers, and, indeed, there are
:al well-documented observations of
:ciable gain obtained in the 10- to
n range.
2. All successful setups used
ıdrical geometries. In principle,
arrangements could be scaled up
ly to give higher gains, but there
›roblems with the proper optics.
3. The systems currently studied
low efficiency. Since one easily
out of laser power, conditions must
ptimized with an eye on sticking to
ly small-size lasers for sources.
4. The wavelength presently achiev-
is somewhat too long for practical
ications (too much will be absorb-
One ought to aim for not more than
wavelength radiation. That would
sfy, for example, the biologists who
eager to construct an x-ray micro-
e. (There are unconfirmed rumors
this goal has already been achiev-

5. Electron collisional excitation
not seem to work. But Pert sug-
ed that one should try photoexcita-
, about which little experimental
rmation exists, despite encouraging
l computations.

All in all, I find the progress in
area most remarkable, and stronger
lvement of our talented European
eagues in US efforts should be a
er of concern.

The concluding talk of the symposi-
as delivered by Professor R. Wallen-
n, who reported on work done by a
e group of researchers at the Uni-
versity of Bielefeld, West Germany. This research approach is quite different from the other, direct-generation methods. It is, strictly speaking, sophisticated work in the area of electro-optics, and it aims at generating broadly tunable VUV (or at least hard UV) radiation by nonlinear frequency mixing in rare atom gases and in metal vapors. The merit of the approach is to avoid or rather to circumvent the problems of direct generation of energetic, highly coherent radiation (with little hope, though, to get down into the x-ray region), and it has received much interest in the past few years. I was somewhat surprised that Wallenstein did not give credit to other groups working in this area, and in fact he did not preface his progress report by a general introduction.

Wallenstein began by recalling that because of the phase-matching conditions, the tuning range of the sum-frequency method is restricted to spectral regions of negative phase-mismatch. Therefore, frequency tripling and sum-frequency mixing in the rare gases and in mercury vapor can provide hard UV radiation only in the spectral region 72 to 185 nm, where these substances indeed have negative dispersion. These earlier experiments of the Bielefeld group were more recently followed by utilizing difference-frequency mixing, which is not restricted by the dispersion of the medium. In this way, the scientists could generate VUV radiation in the range of 120 to 200 nm. They investigated a large variety of possibilities in this category. They used a Nd/Yag laser in the fundamental mode (frequency ω_{IR}) to pump a dye laser system with visible output (frequency ω_1), which was tuned from 540 to 670 nm. If we denote the frequency-doubled dye laser radiation frequency by ω_{UV} ($\equiv 2\omega_1$), then the third-order mixings studied were as follows:

$$2\omega_{UV} - \omega_1,\ 2\omega_{UV} - \omega_{IR},\ 2(\omega_{UV} + \omega_{IR}) - \omega_1,$$
$$\text{and } 2(\omega_{UV} + \omega_{IR}) - \omega_{IR}.$$

The Bielefeld group found that at laser pulse powers of a few megawatts, the

efficiency of the conversion was, in general, only 10^{-5} to 10^{-6}. However, if they tuned the laser frequency to a two-photon resonance, then, even at relatively low input powers of 10 to 100 kW, the resonant enhancement provided much higher conversion efficiencies, of order 10^{-3} to 10^{-4}.

With these two-photon resonant third order frequency mixing experiments, the scientists succeeded in producing tunable VUV pulses between 72 nm and about 180 nm. They used Hg, Xe, and Kr for mixing media, and the dye laser was operated between 270 to 730 nm. Here also a variety of mixing arrangements were used, for example $2\omega_R-\omega_1$ (where ω_R is tuned to the 4p-5p two-photon resonance of Kr (λ_R = 216.6 nm). Other experiments used: $2\omega_R - (\omega_1 + \omega_{IR})$ and $2\omega_R - 2\omega_1$. In optimal conditions, an input of P_1 = 1 MW and P_R = 200 kW produced VUV pulses close to 0.5 kW.

The most recent and very remarkable experiments of the Bielefeld group progressed to the application of fifth-order mixing processes. In particular, they used resonant mixing in Ar. The VUV wavelength range so covered lies between 42 and 72 nm, and they succeeded in producing pulses with 10^9 photons in each.

Wallenstein concluded his talk by mentioning briefly his plans for the future. The group now wants to conduct frequency tripling experiments with continuous operation in magnesium vapor. This will require the use of a dye ring laser arrangement.

It is not possible to summarize the picture one could gain from the hard-radiation symposium, since the topics treated do not allow for comparison. Surely it is difficult to make spectacular progress in the short- and very short-wavelength regime of coherent radiation sources. But this is not a forgotten area, and some significant progress (and, possibly, an unpublished breakthrough) has been achieved recently. Continued and task-focused support of this field is surely indicated.

3 CONCLUSION

The Second ECAMP clearly and unambiguously demonstrated the vigor and broad base of exciting, contemporary, multidisciplinary research, both experimental and theoretical, in an area that, when my generation worked for their physics degrees, was considered to be hardly more than a somewhat boring, albeit historically decisive, relic of the past. It may be interesting to note that the revival and rapid development of the field came from external stimuli: microwave electronics, optics, optoelectronics, and, of course, the demands on practical development of all sorts of lasers. Large-scale mathematical modeling (as opposed to just massive number-crunching calculations) was made possible by later-generation computers. The atmosphere became ripe, and is still stimulating, to launch novel, always interesting, often technology-oriented, and sometimes spectacular new endeavors.

While all participants left Amsterdam with a sense of satisfaction, some also commented on the lack of any truly "sensational" new breakthroughs. Perhaps the frequent repetition rate is more than adequate to cover the field in its entirety.

APPENDIX A: ORALLY PRESENTED TALKS

Lectures

S. Haroche, Rydberg atoms and molecules: how much did we learn until now?

H. Winter, Electron capture by multicharged ions; status, prospects, and applications.

N. Andersen, Shapes of atoms in collisions.

H. Haberland, Cluster-systems between atoms and solids.

C.J. Joachain, Recent developments in the theory of electron-atom collisions.

Reviews

H. Hotop, Ionization in thermal energy collisions with laser-excited atoms.

J. Kessler, Exploration of spin-dependent interactions using polarized electrons.

P.E. Toschek, Th. Sauter, and W. Neuhauser, Laser spectroscopy for an optical atomic clock.

W. Hogervorst, Progress on the spectroscopy of two-electron atoms.

M. Charlton, Applications of positron beams in atomic physics.

D.P. de Bruijn, Dissociative processes in small molecules, studied with translational spectroscopy.

L. Wöste, Spectroscopy and dynamic properties of metal atom clusters.

B. Poelsema, Thermal energy atom scattering from atoms absorbed on surfaces.

F. Vecchiocattivi, Experimental determination of anisotropic potentials for simple systems.

Progress Reports

D. Gauyacq, Probing highly excited states of small molecules by optical-optical double resonance multiphoton ionization.

W. Radloff, V. Stert, and H.H. Ritze, Characteristics of IR multiphoton excitation in supersonic molecular beams.

P. Zoller, Autoionizing states in intense laser fields.

A. L'Huillier, L.A. Lompré, G. Mainfray, and C. Manus, Multicharged ions in multiphoton ionization.

G. Nienhuis, Radiative transitions during atomic collisions.

D. Delande and J.C. Gay, Rydberg atoms in external fields--a tunable atomic system.

A. Holle, H. Rottke, and K.H. Welge, Laser spectroscopy of the hydrogen atom in strong electric and magnetic fields.

H. Schmidt, Polarization studies in charge transfer collisions with laser excited atoms.

J.P. Gauyacq, Theory of associative detachment and dissociative attachment.

I.I. Sobelman, Parity violation in atomic physics.

P.G. Burke, Low energy electron molecule scattering.

P. Connerade, The VUV is more exciting.

V. Schmidt, Photoionization of free metal atoms using synchrotron radiation.

T.R. Govers, P.M. Guyon, and T. Baer, State-selected ion-molecule reactions.

P.J. Sarre, Laser photofragment spectroscopy of molecular ions.

B. Wilhelmi, Study of molecular motion by ultrashort light pulses.

A.W. Kleyn, Rainbows in gas-phase and surface scattering.

C.R. Vidal, Accurate determination of potential energy curves.

C.A. Nicolaides, Electron correlation and relativity in excited states of atoms and molecules. Applications of a state specific theory.

Symposia

1. Multiply Charged Ions

L.H. Andersen, Transfer ionization--an alternative process after transfer of two electrons.

A. Bordenave-Montesquieu, Autoionization in charge exchange between multi-charged ions and two-electron targets, at low collision velocity.

P. Defrance, Recent experimental results of electron impact.

A.P. Shergin and V.V. Afrosimov, Auger electron emission from quasimolecules.

2. New Techniques for Generating Coherent VUV and XUV

M. Billardon, Free electron laser in the visible. Generation of coherent emission in the short wavelength range.

G. Pert, XUV lasers--a review.

R. Hilbig, G. Hiller, A. Lago, A. Timmermann, and R. Wallenstein, Broadly tunable VUV radiation generated by frequency mixing in gases.

Hot Topics

P. Hammond, F.H. Read, S. Cvejanovic, and G.C. King, Energy partitioning in near-threshold excitation.

P. van der Straten, P.M. Koenraad, R. Morgenstern, and A. Niehaus, Angular correlations of autoionization electrons from Li^++He collisions and their time dependence.

W. Keller, H. Morgner, and W. Müller, Probing the outermost layer of a free liquid surface: electron spectroscopy of formamide under He(2^3S) impact.

H. Rinneberg, G. Jönsson, J. Neukammer, K. Vietzke, H. Hieronymus, and A. König, Autoionization inhibited by internal interferences.

M. Pinard, P. Verkerk, and C. Grynberg, Spectroscopy of atoms dressed by optical photons in nearly degenerate four-wave mixing.

V.I. Balykin, V.S. Letokhov, V.G. Minogin, A.I. Sidorov, and T.V. Zueva, Collimation of atomic beam by resonant laser radiation pressure.

K. Müller-Dethlefs, M. Sander, and L.A. Chewter, Site specific ionic fragmentation of molecules following inner-shell excitation by soft x-ray synchroton radiation.

E. Gottwald, A. Mattheus, U. Hefter, and K. Bergmann, Vibrational-rotational excitation in Na_2-X collisions.

F. Martin, A. Reira, and M. Yanez, Dynamical coupling in the framework of the Feshbach method. Application to $LiHe^{3+}$ quasimolecule.

M. Defour, J.C. Keller, J.L. le Gouët, and M. Saidi, Stimulated photon echo for angular analysis of elastic and inelastic collisional processes.

APPENDIX B: AREAS COVERED BY POSTER PRESENTATIONS

Laser spectroscopy and laser-atom interactions.
Spectroscopy of neutral atoms and ions.
Atoms in external fields.
Lifetimes and transition probabilities.
Rydberg states.
Theory of atomic structure.
Photoionization, photoelectron spectroscopy, photodissociation.
Multiphoton ionization/dissociation.
Molecular spectra: visible, ultraviolet, infrared, large molecules, condensed matter, clusters, matrix spectroscopy.
Electron (positron) impact processes: four sessions with diverse topics.
Collisions of atoms, ions, and molecules: three sessions with diverse topics.
Reactive collisions and chemical reactions.
Collisions of ions with atoms and molecules: three sessions with diverse topics.
Collisions in external radiation fields.
Gaseous electronics and plasmas.
Methods, techniques, instruments.

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